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Technical Report

Drop-Weight Tests of Experimental HY-130/150 Steels

Applied Research Laboratory
United States Steel
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DROP-WEIGHT TESTS OF EXPERIMENTAL HY-130/150 STEELS
(40.018-001)(19)(a-AS-NP-36)(S-13313)

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Approved by J. H. Gross, Division Chief

Abstract

One of the most important requirements of HY-130/150 steels and weldments is high fracture toughness. For laboratory screening of experimental steels, fracture toughness can be most conveniently determined from Charpy V-notch impact tests. However, fracture-toughness values obtained from drop-weight and explosion-bulge tests are also important, and correlations between these tests and the Charpy V-notch test have not been established for steels having yield strengths in the range 130 to 150 ksi. Therefore, the Applied Research Laboratory of US Steel conducted Charpy V-notch and drop-weight tests on 1/2- and 1-inch-thick plates of four experimental HY-130/150 steels ($3\frac{3}{4}$Ni-Cr-Mo-V, $5\frac{1}{4}$Ni-Cr-Mo-V, 5Ni-Cr-Mo-V, and $7\frac{1}{2}$Ni-Cr-Mo steels) and HY-80 steel (heat-treated to a yield strength of 150 ksi) to determine the relation between Charpy V-notch and drop-weight test criteria and to determine the best method for obtaining fracture-toughness values to screen experimental HY-130/150 steels. end

The results indicated that for HY-130/150 type steels, the drop-weight test nil-ductility temperature (NDT) can be estimated from Charpy V-notch test data by determining the temperature corresponding to an energy absorption of about 40 ft-lb, a shear fracture of about 50 percent, or a lateral expansion of about 20 mils. The results also indicated that the explosion-bulge test fracture-transition-plastic temperature (FTP) (determined by adding 120 F to the NDT) is approximately the same as the 100 percent shear-fracture temperature in the Charpy V-notch test. Because the NDT and FTP temperatures estimated from the Charpy V-notch test values were significantly in error for several of the steels, additional study would be required to establish a correlation that would be useful in service. However, for laboratory screening where the test material is limited, acceptable approximations of the NDT and FTP can be obtained from Charpy V-notch test data.

Introduction

One of the most important requirements of HY-130/150 steels and weldments is high fracture toughness. Although fracture toughness is reported in various ways, for steels with yield strengths in the range 130 to 150 ksi, it is most commonly reported (1) in terms of the energy absorption, fracture appearance, or lateral expansion of Charpy V-notch impact test specimens; (2) in terms of the nil-ductility temperature (NDT) of drop-weight test specimens, or the NDT, fracture-transition-elastic (FTE), and fracture-transition-plastic (FTP) temperatures of explosion-bulge test specimens; and (3) in terms of various drop-weight-tear or explosion-tear test criteria.

For Laboratory screening of small heats, the most convenient test is the Charpy V-notch impact test because it requires a very small quantity of test material and because 1/2 inch is the maximum plate thickness generally produced in Laboratory heats. However, reliable correlations between Charpy V-notch impact test criteria and drop-weight, explosion-bulge, drop-weight-tear, or explosion-tear test criteria have not been established for steels having yield strengths in the range 130 to 150 ksi. Therefore, as part of a program to determine the types of tests that should be employed to obtain fracture-toughness values during Laboratory screening of experimental HY-130/150 steels, the Applied Research Laboratory conducted

Charpy V-notch impact tests and drop-weight tests on 1/2- and 1-inch-thick plates of five experimental HY-130/150 steels,[1,2]* including a recently developed 5Ni-Cr-Mo-V steel[3,4] that is considered to be extremely promising as an HY-130/150 steel.

The present report summarizes the results of these tests and makes recommendations concerning the use of Charpy V-notch impact test results for obtaining fracture-toughness values during Laboratory screening of experimental HY-130/150 steels.

Materials and Experimental Work

The steels used in the present investigation (HY-80, 3¾Ni-Cr-Mo-V, 5¼Ni-Cr-Mo-V, 7½Ni-Cr-Mo) were melted at Duquesne Works in the basic electric furnace and subsequently rolled and heat-treated at Homestead Works.[1] The 1-inch-thick plates of HY-80 steel were rolled at the Laboratory from 2-inch-thick plates and reheat-treated at the Laboratory because 1-inch-thick mill-produced plate was not available. The 1/2-inch-thick plates of the 5Ni-Cr-Mo-V steel were melted, rolled, and heat-treated at the Laboratory[3] and the 1-inch-thick plates of the 5Ni-Cr-Mo-V steel were melted at Duquesne Works and rolled and heat-treated at Homestead Works.[4] The chemical composition of the steels is shown in Table I.

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*See References.

Preparation of Drop-Weight Test Specimens

The drop-weight specimens for both the 1/2- and 1-inch-thick plates were prepared in the following manner:

1. The specimen blanks (1 by 3-1/2 by 14 inches or 1/2 by 2 by 5 inches) were machined.

2. The standard Hardex N weld bead was deposited.

3. The plates were reheat-treated after welding. (Details of the heat treatments are presented in Appendix A.)

4. The weld beads were notched in the standard manner.[5)]

Preparation of Tension and Impact Test Specimens

After the plates were tested, duplicate 0.252-inch-diameter tension test specimens for each steel were machined from a broken 1-inch-thick drop-weight test specimen. Since the exact tensile properties were not essential and because hardness measurements showed similar strength levels for the 1/2- and 1-inch-thick plates, tension tests were conducted only on 1-inch-thick plate material. The yield strength of the HY-80 steel was about 93 ksi, and the yield strengths of the experimental HY-130/150 steels ranged from about 143 ksi to 152 ksi as shown in Table II.

Charpy V-notch impact test specimens were machined from broken drop-weight test specimens. Impact data were obtained for all steels at temperatures ranging from +80 to -320 F.

Drop-Weight Test Procedure

The 1/2-inch-thick drop-weight specimens were tested using a procedure[5] developed by the Naval Research Laboratory (NRL): a stop distance of 0.09 inch, a support span of 4.0 inches, and a weight of 60 pounds. The 1-inch-thick drop-weight specimens were tested using the NRL standard method,[6] which has now been adopted by ASTM (E208-63T): a stop distance of 0.30 inch, a support span of 12 inches, and a weight of 100 pounds.

Results and Discussion

Drop-Weight Tests

The results of the individual drop-weight tests for the five steels are tabulated in Appendix B for the 1-inch-thick plates and in Appendix C for the 1/2-inch-thick plates, and the nil-ductility temperatures (NDT) are summarized in Table III. The results show that when the yield strength of the HY-80 steel was increased from 93 ksi to 152 ksi, the NDT of the 1/2- and the 1-inch-thick plates increased 90 F. Thus, for a given steel, an increase in yield strength may be expected to raise the NDT.

For the five experimental HY-130/150 steels, the NDT ranged from -100 F to -250 F for the 1/2-inch-thick plates and from -60 F to -200 F for the 1-inch-thick plates. As shown in Figure 1, the NDT of the

1/2- and 1-inch-thick plates of the experimental HY-130/150 steels decreased as the nickel content increased. On the basis of these limited data, the NDT appears to be lowered about 35 F for each 1 percent increase in the nickel content.

The data also indicate that the NDT of the 1/2-inch-thick test specimens averaged about 50 F lower than that of the 1-inch-thick test specimens. These differences are related to differences in the Charpy V-notch impact test results as discussed later. Similar observations on the effect of specimen thickness on NDT have been previously reported.[7,8)]

Relation Between NDT and Charpy V-Notch Impact Test Properties

The Charpy V-notch impact test curves for the five steels are shown in Figures 2 through 7 for the 1/2-inch-thick plates and in Figures 8 through 13 for the 1-inch-thick plates. For each of the steels, the energy absorption, the percent shear fracture, and the lateral expansion values corresponding to the NDT were determined from the appropriate Charpy V-notch impact test curve, and the values are summarized in Table IV. The summary shows that at the NDT, the energy absorption for the 1/2-inch-thick plates of the experimental HY-130/150 steels varied from 22 to 70 ft-lb and averaged 42 ±16 ft-lb; for the 1-inch-thick plates the variation was 23 to 65 ft-lb and the average was 43 ±16 ft-lb.

At the NDT, the percent shear varied from 27 to 65 percent (average of 44 ±14 percent) for the 1/2-inch-thick plates and from 43 to

68 percent (average of 51 ±7 percent) for the 1-inch-thick plates. For lateral expansion, the variation was 5 to 37 mils (average of 20 ±11 mils) for the 1/2-inch-thick plates and 9 to 30 mils (average of 20 ±8 mils) for the 1-inch-thick plates. Thus, the notch toughness of the 1/2-inch-thick plates was better than that of the corresponding 1-inch-thick plates and accounts, at least in part, for lower NDT's of 1/2-inch-thick plates. Although these data are limited, they indicate that the NDT for quenched and tempered alloy steels having a yield strength in the range 140 to 150 ksi can be best estimated from Charpy V-notch data by determining the temperature corresponding to an energy absorption of about 40 ft-lb, a shear fracture of about 50 percent, or a lateral exapnsion of about 20 mils. These Charpy V-notch correlations with the NDT agree quite well with those predicted in previous investigations.[3,9,10)]

The accuracy with which the NDT can be predicted using the suggested correlations (40 ft-lb energy absorption, 50 percent shear fracture, and 20 mils lateral expansion) is shown in Table V. Among the steels, the NDT of the 5¼Ni-Cr-Mo-V steel was almost exactly predicted and that of the 5Ni-Cr-Mo-V steel was satisfactorily predicted, whereas those of the HY-80 and the 7½Ni-Cr-Mo steels were higher and that of the 3¾Ni-Cr-Mo-V steel was lower than the actual NDT values. Among the various criteria used to predict the NDT, the 50 percent shear fracture criterion provided the best prediction (maximum error of 45 F), whereas significantly larger errors were observed when the 40 ft-lb energy absorption or the 20 mils lateral expansion criterion was used. The results indicate that additional data are necessary to establish a reliable correlation. However, for Laboratory screening purposes, the Charpy V-notch test can be used to estimate the NDT for HY-130/150 steels.

The relation between the NDT and the Charpy V-notch impact test temperature corresponding to 100 percent shear fracture is shown in Table VI. The results for HY-80 steel show that the difference between the NDT and the 100 percent shear-fracture temperature increased 70 F for the 1/2- and the 1-inch-thick plates when the yield strength was increased from 93 ksi to 152 ksi. As previously noted, the increase in yield strength raised the NDT by 90 F; however, the 100 percent shear-fracture temperature was raised by 160 F. Thus the shear-fracture temperature in the Charpy V-notch test was more sensitive to increased yield strength than was the NDT in the drop-weight test.

For the experimental HY-130/150 steels, the difference between the NDT and the 100 percent shear-fracture temperature varied from 120 F to 170 F and averaged 142 ±20 F for the 1/2-inch-thick plates. For the 1-inch-thick plates the variation was 120 F to 180 F and the average was 136 ±27 F. Thus, the difference between the NDT and the 100 percent shear-fracture temperature was about 140 F for steels with yield strengths in the range 140 to 150 ksi. The difference of 140 F between the NDT and 100 percent shear-fracture temperature agrees well with the difference (120 F) between the NDT and the FTP reported[11] by Pellini and Puzak for steels having yield strengths up to about 100 ksi. The results suggest that for screening purposes, the Charpy V-notch 100 percent shear-fracture temperature can be used to estimate the FTP temperature for HY-130/150 type steels. However, until this relation is confirmed in explosion-bulge tests, estimation of FTP from the 100 percent shear-fracture temperature should be limited to screening tests on experimental HY-130/150 steels for which sufficient material for drop-weight or explosion-bulge tests is not available.

Summary

The present study was conducted to determine the relation between Charpy V-notch impact test results and drop-weight test results of five promising HY-130/150 high-strength steels (HY-80, $3\frac{3}{4}$Ni-Cr-Mo-V, $5\frac{1}{4}$Ni-Cr-Mo-V, 5Ni-Cr-Mo-V, and $7\frac{1}{2}$Ni-Cr-Mo steels), and to determine the best method for obtaining fracture-toughness values to screen experimental HY-130/150 steels. The results may be summarized as follows:

1. The average absorbed energy, percent shear fracture, and lateral expansion observed in the Charpy V-notch impact test at NDT for the 1-inch-thick plates of the five steels were 43 ft-lb, 51 percent shear, and 20 mils, respectively.

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2. The average absorbed energy, percent shear fracture, and lateral expansion at NDT for the 1/2-inch-thick plates of the five steels were 42 ft-lb, 44 percent shear, and 20 mils, respectively.

3. NDT values for the 1/2-inch-thick plates were 40 to 60 F lower than those for the 1-inch-thick plates. However, correspondingly better toughness for the 1/2-inch-thick compared with the 1-inch-thick plates was observed in the Charpy V-notch impact tests.

4. The average difference between NDT and the 100 percent shear-fracture temperature measured in a Charpy V-notch impact test was 140 degrees for both the 1/2- and 1-inch-thick plates.

5. The NDT for all the experimental HY-130/150 steels decreased as nickel content increased.

6. The NDT of 1-inch-thick plates of the recently developed 5Ni-Cr-Mo-V steel was -120 F.

The preliminary results obtained on the steels investigated were not sufficient to establish definite correlations between the NDT and various Charpy V-notch criteria. However, for Laboratory screening purposes, prediction of the NDT from Charpy V-notch test criteria appears to be satisfactory. In addition, prediction of the FTP from the 100 percent shear-fracture temperature in the Charpy V-notch test also appears to be satisfactory for Laboratory screening purposes.

End

Recommendations and Future Work

Because the NDT can be estimated from Charpy V-notch impact test results with sufficient accuracy for screening purposes, the testing of 1/2-inch-thick drop-weight specimens to screen Laboratory heats is not recommended.

References

1. D. S. Dabkowski, S. J. Manganello, and L. F. Porter, "The Effect of Heat Treatment on the Strength and Toughness of Promising 130 to 150 Ksi Yield-Strength Submarine-Hull Steels," Applied Research Laboratory Progress Report, Project No. 40.18-001(1), March 20, 1963.

2. L. F. Porter, A. M. Rathbone, S. T. Rolfe, and A. Lesnewich, "Preliminary Status Report: Development of an HY-130/150 Weldment," Applied Research Laboratory Progress Report 40.18-001(6), (S-10000), May 31, 1963.

3. S. J. Manganello and L. F. Porter, "Evaluation of the Hardenability, Temperability, and Mechanical Properties of Ten 5Ni-Cr-Mo Steels," Applied Research Laboratory Progress Report, Project No. 40.18-001(9), (S-11109-1), September 20, 1963.

4. S. J. Manganello, L. F. Porter, and G. E. Loveday, "Production and Properties of 5Ni-Cr-Mo-V Steel Plates," Applied Research Laboratory Progress Report, Project No. 40.18-001(16), (S-11104-2), January 2, 1964.

5. P. P. Puzak and A. J. Babeck, "Normalization Procedures for NRL Drop-Weight Test," <u>Welding Journal</u>, 38 (5), Research Suppl., 209-s to 218-s, (1959).

6. P. P. Puzak and W. S. Pellini, "Standard Method for NRL Drop-Weight Test," NRL Report 5831, August 21, 1962.

7. R. W. Vanderbeck, "Mechanical Properties of High-Manganese Semikilled Steel Plate," SSC Report Serial No. SSC-144, January 2, 1963.

8. S. A. Agnew, M. D. Mittleman, and R. D. Stout, "Some Observations on the Kinzel and Drop-Weight Tests," <u>Welding Journal</u>, 39 (5), Research Suppl., 205-211, (1960).

9. J. H. Gross and R. D. Stout, "Ductility and Energy Relations in Charpy Tests of Structural Steels," <u>Welding Journal</u>, 37 (4), Research Suppl., 151-s to 159-s (1958).

(Continued)

References (Continued)

10. J. H. Gross, "Comparison of Charpy V-Notch and Drop-Weight Tests for Structural Steels," Welding Journal, 39 (2), Research Suppl., 59-69, (1960).

11. W. S. Pellini and P. P. Puzak, "Practical Considerations in Applying Laboratory Fracture Test Criteria to the Fracture-Safe Design of Pressure Vessels," NRL Report 6030, November 5, 1963.

APPENDICES

A. Heat Treatment

B. NDT Results for 1-Inch-Thick Plates

C. NDT Results for 1/2-Inch-Thick Plates

APPENDIX A

Heat Treatment

For each steel, the 1-inch-thick plate specimens were austenitized for 1 hour, water-quenched, tempered for 1 hour, and then water-quenched, at the following temperatures:

Steel	Austenitizing Temp, F	Tempering Temp, F
HY-80	1650	1280
HY-80 heat-treated to 150 ksi	1650	1040
3¾Ni-Cr-Mo-V	1500	1100
5¼Ni-Cr-Mo-V	1450	1170
7½Ni-Cr-Mo	1475	1115
5Ni-Cr-Mo-V production heat	1500	1100

The 1/2-inch-thick plates were austenitized for 1/2 hour, water-quenched, tempered for 1/2 hour, and then water-quenched, at the following temperatures:

Steel	Austenitizing Temp, F	Tempering Temp, F
HY-80	1650	1255
HY-80 heat-treated to 150 ksi	1650	1015
3¾Ni-Cr-Mo-V	1500	1080
5¼Ni-Cr-Mo-V	1450	1150
7½Ni-Cr-Mo	1475	1095
5Ni-Cr-Mo-V Laboratory heat	1500	1050

APPENDIX B

NDT Results for 1-Inch-Thick Plates

HY-80

Test Temperature, F	Test Result*
-140	00
-150	XX
-160	X0
-180	X
-200	X

NDT = -150

HY-80 Heat-Treated to 150 Ksi

Test Temperature, F	Test Result*
0	0
- 40	00
- 50	00
- 60	XX
-100	X

NDT = -60

$3\frac{3}{4}$Ni-Cr-Mo-V

Test Temperature, F	Test Result*
- 80	00
- 90	000
-100	X0
-110	XX
-120	X
-160	X

NDT = -100

$5\frac{1}{4}$Ni-Cr-Mo-V

Test Temperature, F	Test Result*
-120	0
-140	0
-150	00
-160	00X

NDT = -160

$7\frac{1}{2}$Ni-Cr-Mo

Test Temperature, F	Test Result*
-160	0
-190	000
-200	0XX
-210	X
-220	XX
-240	XX

NDT = -200

5Ni-Cr-Mo-V Production Heat

Test Temperature, F	Test Result*
-100	000
-110	000
-120	X
-140	X

NDT = -120

*0 indicates no failure of the specimen and X indicates failure.

APPENDIX C

NDT Results for 1/2-Inch-Thick Plates

HY-80

Test Temperature, F	Test Result*
-160	0
-200	00
-210	X
-220	X
-230	X

NDT = -210

HY-80 Heat-Treated to 150 Ksi

Test Temperature, F	Test Result*
- 60	0
-100	00
-110	0
-120	X
-140	X

NDT = -120

3¾Ni-Cr-Mo-V

Test Temperature, F	Test Result*
-120	0
-150	00
-160	XX
-170	X

NDT = -160

5¼Ni-Cr-Mo-V

Test Temperature, F	Test Result*
-180	00
-190	00
-200	0X

NDT = -200

7½Ni-Cr-Mo-V

Test Temperature, F	Test Result*
-240	000
-250	X
-260	X
-320	X

NDT = -250

5Ni-Cr-Mo-V Laboratory Heat

Test Temperature, F	Test Result*
- 90	0
-100	00X
-120	0X
-140	X
-180	X

NDT = -100

*0 indicates no failure of the specimen and X indicates failure.

Table I

Chemical Composition of Steels Investigated—Percent
(Check Analyses)

Steel	Heat Number	C	Mn	P	S	Si	Ni	Cr	Mo	V	Al*	N	O
HY-80	X51289	0.13	0.29	0.009	0.011	0.25	2.97	1.60	0.51	<0.01	0.058	0.012	0.002
3¾Ni-Cr-Mo-V	X14331	0.18	0.26	0.009	0.006	0.23	3.67	1.50	0.32	0.10	0.018	0.011	0.003
5¼Ni-Cr-Mo-V	X14332	0.14	0.25	0.008	0.003	0.23	5.04	0.40	0.38	0.07	0.051	0.010	0.003
7½Ni-Cr-Mo	X14043	0.13	0.28	0.006	0.004	0.25	7.43	0.78	1.02	<0.01	0.053	0.011	0.003
5Ni-Cr-Mo-V Laboratory heat	R9078-1	0.09	0.74	0.008	0.007	0.25	5.17	0.55	0.55	0.07	0.021	0.005	0.001
5Ni-Cr-Mo-V production heat	X53185	0.11	0.74	0.007	0.006	0.27	4.98	0.58	0.54	0.064	0.024	0.011	0.002

*Acid soluble.

Table II

Longitudinal Tensile Properties* of Steels Investigated

Steel	Cross-Rolling Ratio	Yield Strength (0.2% Offset), ksi	Tensile Strength, ksi	Elongation in 1 Inch, %	Reduction of Area, %	Yield-Tensile Ratio	Hardness, RC
HY-80	8:1	92.7	108.5	26.5	70.7	0.855	20.2
HY-80 heat-treated to 150 ksi	8:1	151.2	163.4	17.0	53.4	0.926	35.2
3¾Ni-Cr-Mo-V	2:1	147.5	159.4	19.0	70.2	0.925	34.7
5¼Ni-Cr-Mo-V	2:1	143.1	147.2	20.0	68.0	0.973	32.5
7½Ni-Cr-Mo	2:1	151.9	162.5	20.0	67.0	0.934	35.5
5Ni-Cr-Mo-V Laboratory heat	1:1	146.6	157.0	19.8	69.2	0.930	36.5
5Ni-Cr-Mo-V production heat	1:1	149.4	158.0	19.2	69.5	0.946	35.5

*Average of duplicate specimens from 1-inch-thick plates.

Table III

Comparison of NDT Results for 1/2- and 1-Inch-Thick Plates

Steel	1/2-Inch NDT, F	1-Inch NDT, F	Difference, F
HY-80	-210	-150	60
HY-80 heat-treated to 150 ksi	-120	- 60	60
$3\frac{3}{4}$Ni-Cr-Mo-V	-160	-100	60
$5\frac{1}{4}$Ni-Cr-Mo-V	-200	-160	40
$7\frac{1}{2}$Ni-Cr-Mo	-250	-200	50
5Ni-Cr-Mo-V Laboratory heat	-100		*
5Ni-Cr-Mo-V production heat		-120	*

*Values not directly comparable because material was taken from different heats.

Table IV

NDT Results for 1/2-Inch- and 1-Inch-Thick Plates Investigated

Steel	1/2-Inch-Thick Plates				1-Inch-Thick Plates			
		Values at NDT				Values at NDT		
	NDT, F	Energy Absorbed, ft-lb	% Shear	Lateral Expansion, mils	NDT, F	Energy Absorbed, ft-lb	% Shear	Lateral Expansion, mils
HY-80	-210	110	65	60	-150	40	45	25
HY-80 heat-treated to 150 ksi	-120	35	32	10	- 60	23	43	12
3¾Ni-Cr-Mo-V	-160	70	65	37	-100	65	68	28
5¼Ni-Cr-Mo-V	-200	45	50	25	-160	40	50	19
7½Ni-Cr-Mo	-250	22	27	5	-200	30	50	9
5Ni-Cr-Mo-V Laboratory heat	-100	40	45	22				
5Ni-Cr-Mo-V production heat					-120	58	43	30
Average of 5 steels at 130/150 ksi level		42	44	20		43	51	20
Standard Deviation, σ		±16	±14	±11		±16	±7	±8

Table V

Predicted Versus Actual NDT Values

Steel	NDT Values Predicted From Charpy Test Results, F: 40 ft-lb Energy Absorption Criterion	50% Shear Fracture Criterion	20 Mils Lateral Expansion Criterion	Actual NDT Values, F
HY-80 steel heat-treated to 150 ksi				
1/2-inch	-110	-100	-105	-120
1-inch	>+ 80	- 50	+ 80	- 60
3¾Ni-Cr-Mo-V				
1/2-inch	-240	-185	-220	-160
1-inch	-160	-130	-130	-100
5¼Ni-Cr-Mo-V				
1/2-inch	-200	-200	-210	-200
1-inch	-160	-160	-160	-160
7½Ni-Cr-Mo				
1/2-inch	-160	-205	-160	-250
1-inch	-150	-200	-120	-200
5Ni-Cr-Mo-V Laboratory heat (1/2-inch)	-100	- 90	-105	-100
5Ni-Cr-Mo-V production heat (1-inch)	-155	-105	-160	-120

(40.018-001)(19)

Table VI

Difference in 100 Percent Shear Fracture and NDT Values for Plates Investigated

Steel	1/2-Inch-Thick Plates NDT, F	1/2-Inch-Thick Plates 100% Shear Fracture, F	1/2-Inch-Thick Plates Difference, F	1-Inch-Thick Plates NDT, F	1-Inch-Thick Plates 100% Shear Fracture, F	1-Inch-Thick Plates Difference, F
HY-80	-210	-160	50	-150	- 80	70
HY-80 heat-treated to 150 ksi	-120	0	120	- 60	+ 80	140
3¾Ni-Cr-Mo-V	-160	- 40	120	-100	0	100
5¼Ni-Cr-Mo-V	-200	- 40	160	-160	- 20	140
7½Ni-Cr-Mo	-250	- 80	170	-200	- 20	180
5Ni-Cr-Mo-V	-100	+ 40	140	-120	0	120
		Average*	142			136
		Standard Deviation, σ	± 20			± 27

*Values are for steels at 140/150 yield-strength level.

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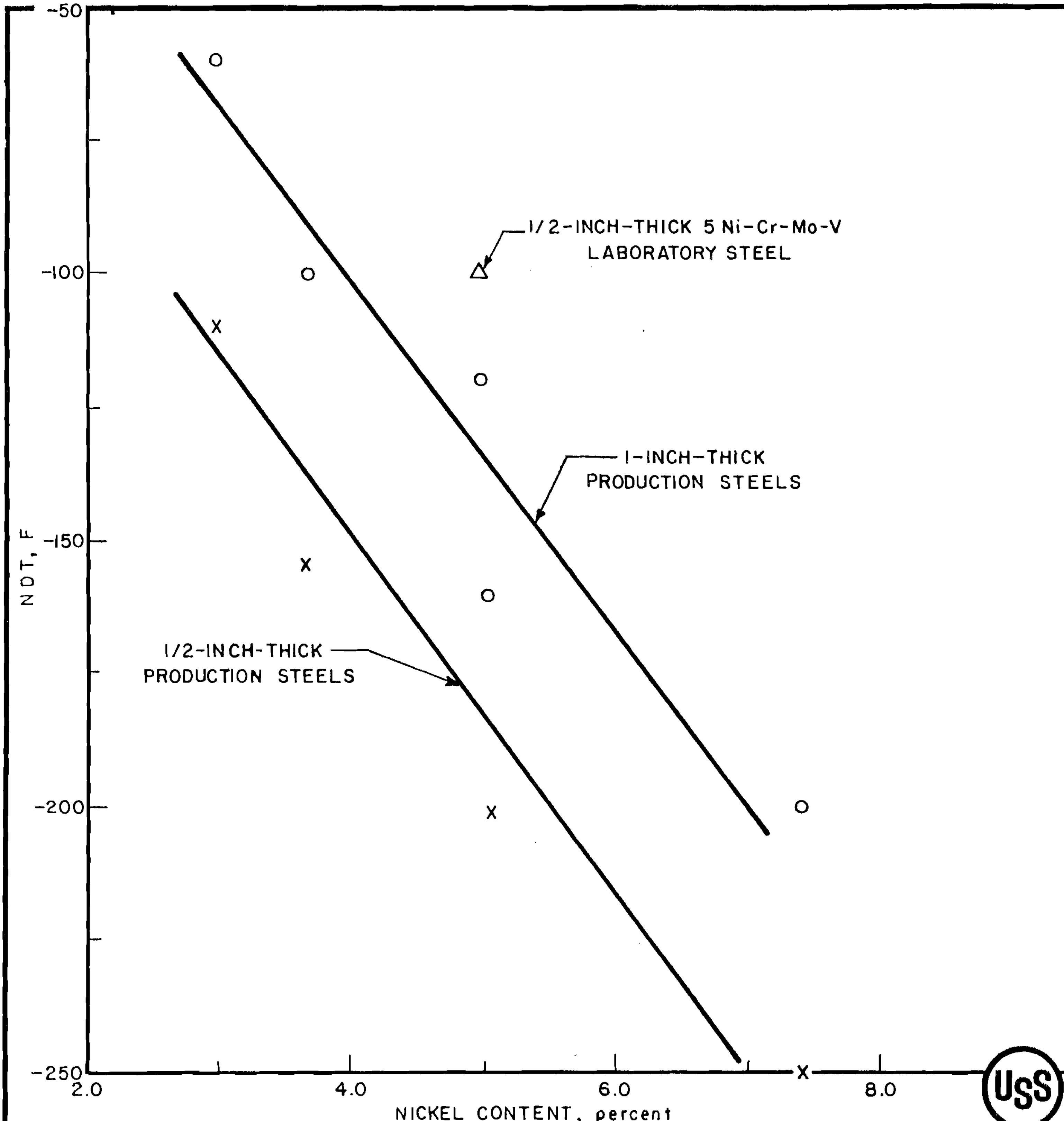

VARIATION IN NIL-DUCTILITY TEMPERATURE WITH NICKEL CONTENT OF STEELS INVESTIGATED

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	1
DRAWING No.		PROJECT No. 40.018-001 (19)	PITTSBURGH, PA.	
ARL 18-303		DATE 3-9-64		

1025 CLEARPRINT PPL.CO. PGH. PA.

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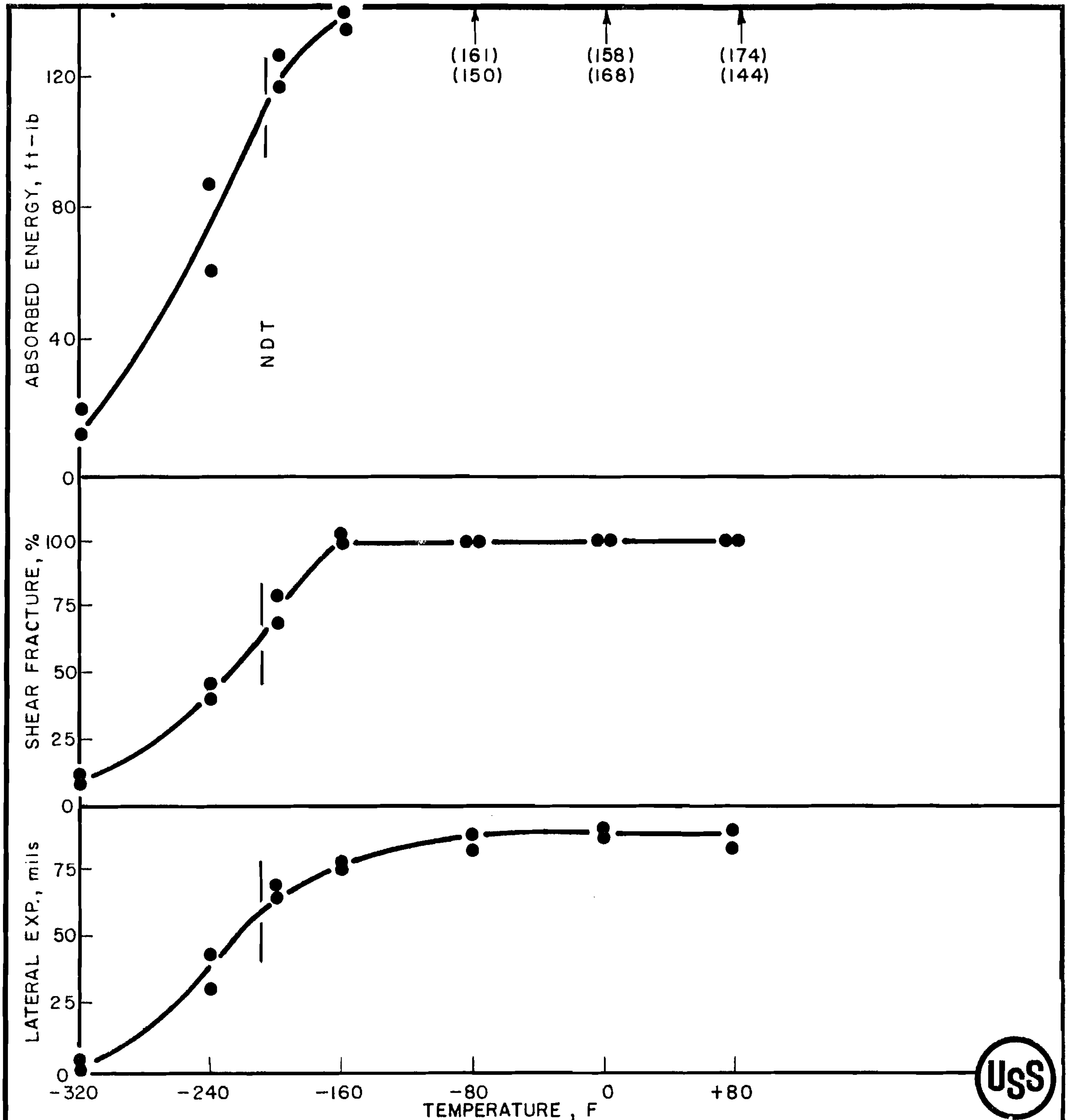
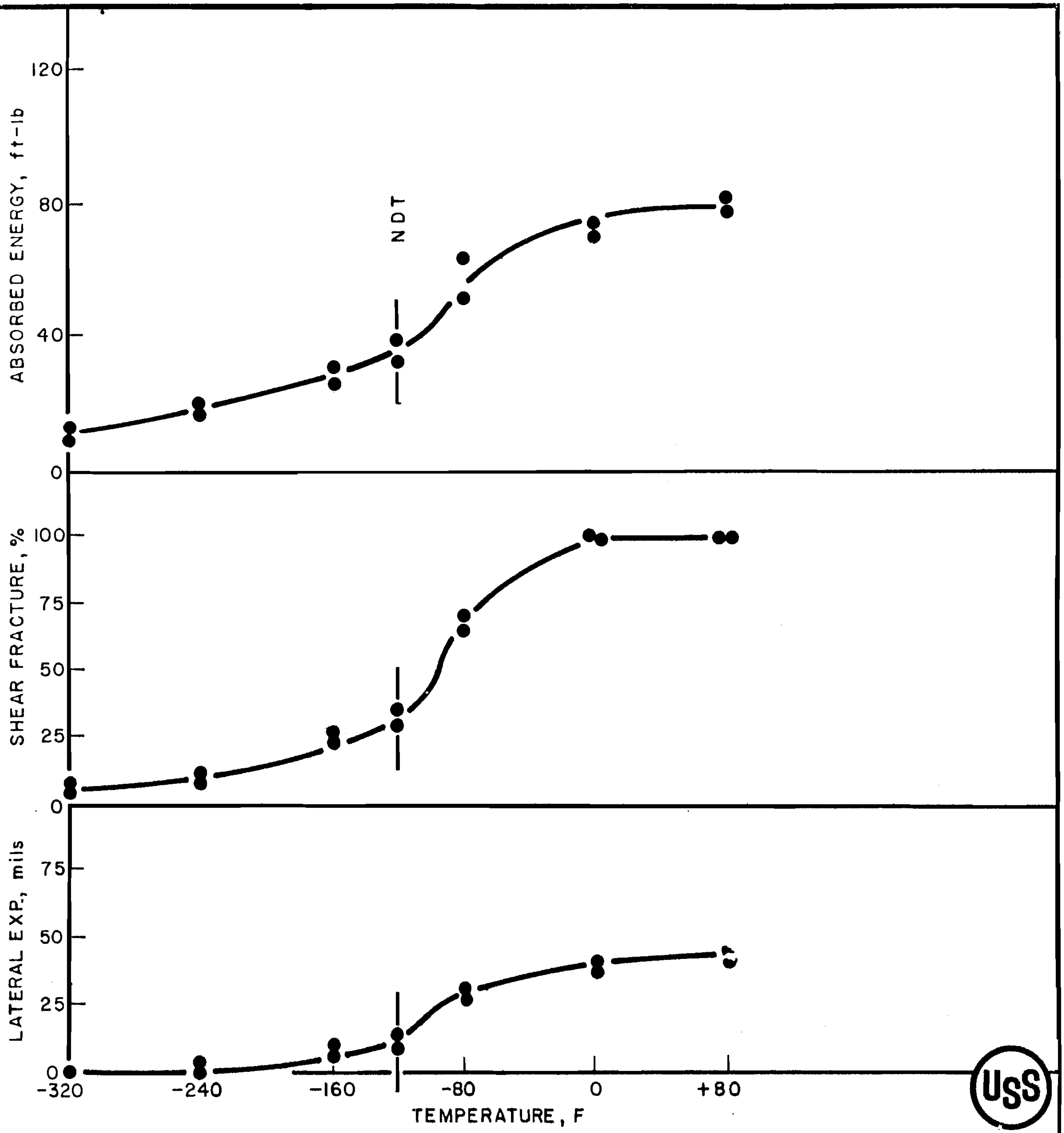


CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1/2-INCH-THICK HY-80 STEEL

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	2
DRAWING No.		PROJECT No. 40.018-001 (19)	PITTSBURGH, PA.	
ARL 18-304		DATE 3-10-64		

1025 CLEARPRINT PPL. CO. PGH. PA.

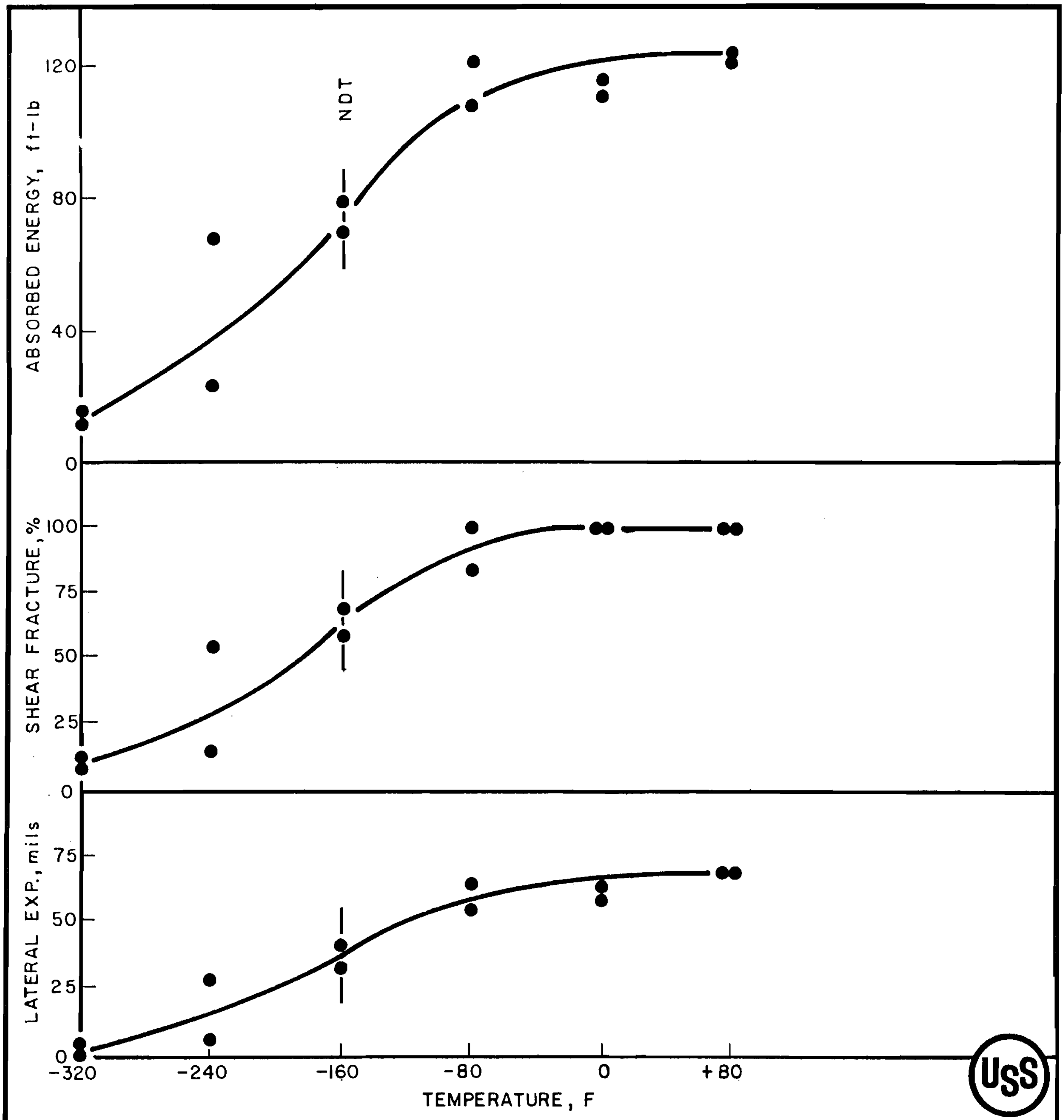
G18242 REV. 357



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1/2-INCH-THICK HY-80 STEEL
HEAT-TREATED TO 150 KSI YIELD STRENGTH

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	3
DRAWING No.		PROJECT No. 40.018-001 (19)	PITTSBURGH, PA.	
ARL 18-305		DATE 3-10-64		

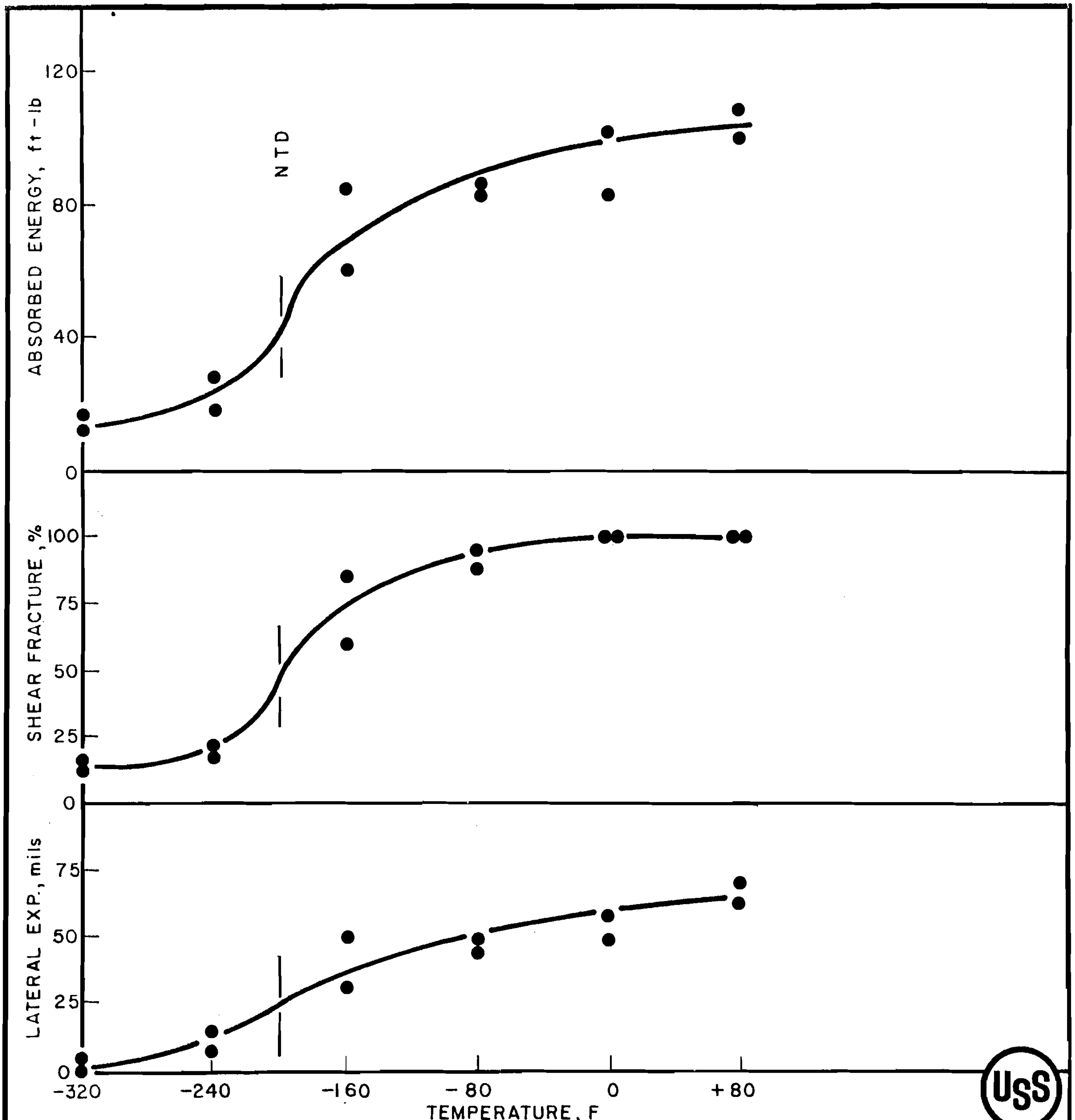
G18242 REV. 357



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1/2-INCH-THICK 3-3/4 Ni-Cr-Mo-V STEEL

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	4
DRAWING No.		PROJECT No. 40.018-001 (19)	PITTSBURGH, PA.	
ARL 18-306		DATE 3-11-64		

G18242 REV. 357



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1/2-INCH-THICK
5-1/4 Ni-Cr-Mo-V STEEL

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	5
DRAWING No.		PROJECT No. 40.018-001(19)	PITTSBURGH, PA.	
ARL 18-307		DATE 3-11-64		

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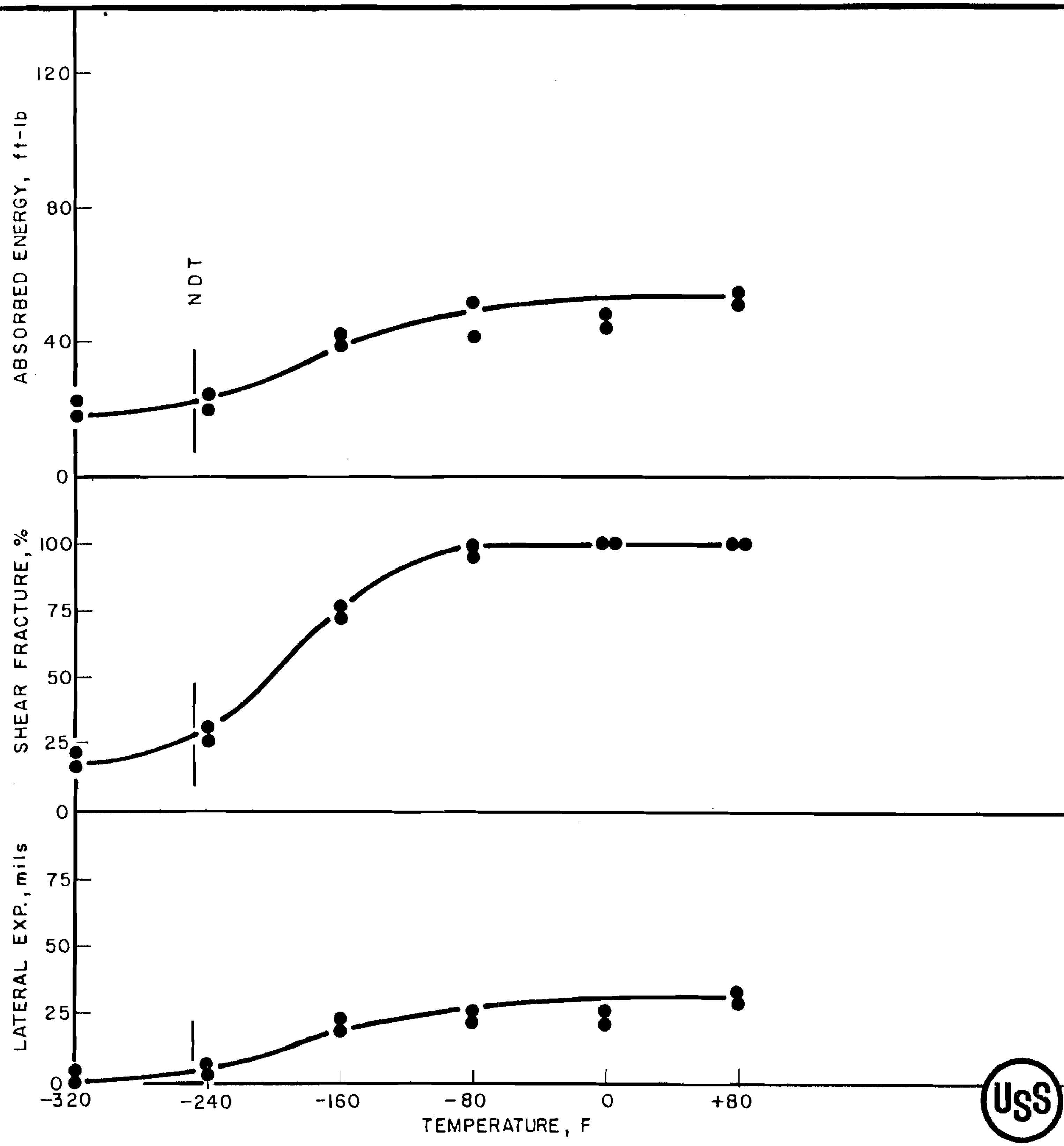
G18242 REV. 357



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1/2-INCH-THICK
7-1/2 Ni-Cr-Mo STEEL

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	6
DRAWING No		PROJECT No. 40,018-001 (19)	PITTSBURGH, PA.	
ARL 18-308		DATE 3-12-64		

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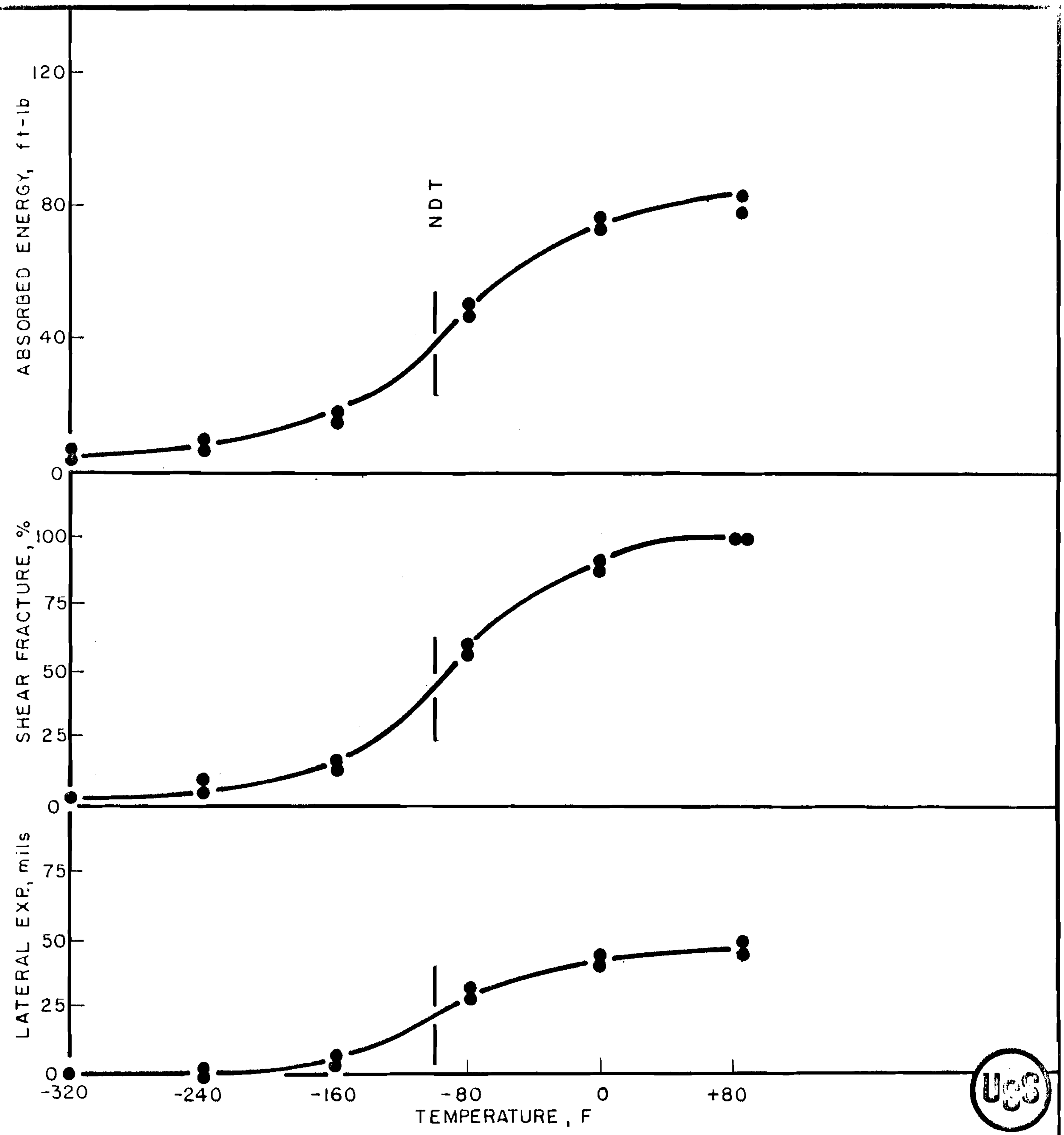
G18242 REV. 357



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1/2-INCH-THICK
5 Ni-Cr-Mo-V LABORATORY HEAT

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	7
DRAWING No.		PROJECT No. 40.018-001(19)	PITTSBURGH, PA.	
ARL 18-309		DATE 3-12-64		

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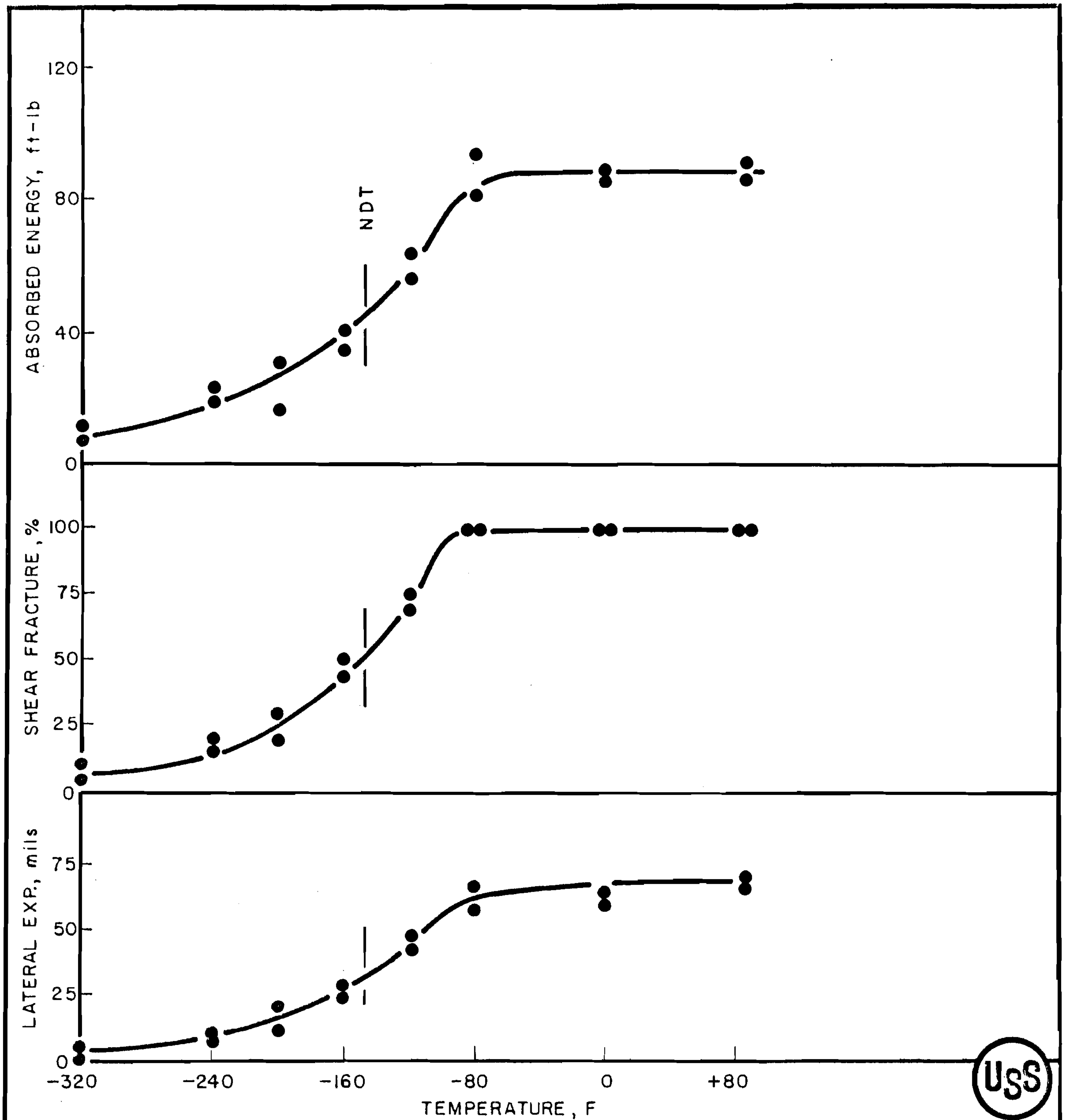
G18242 REV. 357



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1-INCH-THICK HY-80 STEEL

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	8
DRAWING No		PROJECT No	PITTSBURGH, PA.	
ARL 18-310		40.018-001 (19)		
		DATE		
		3-10-64		

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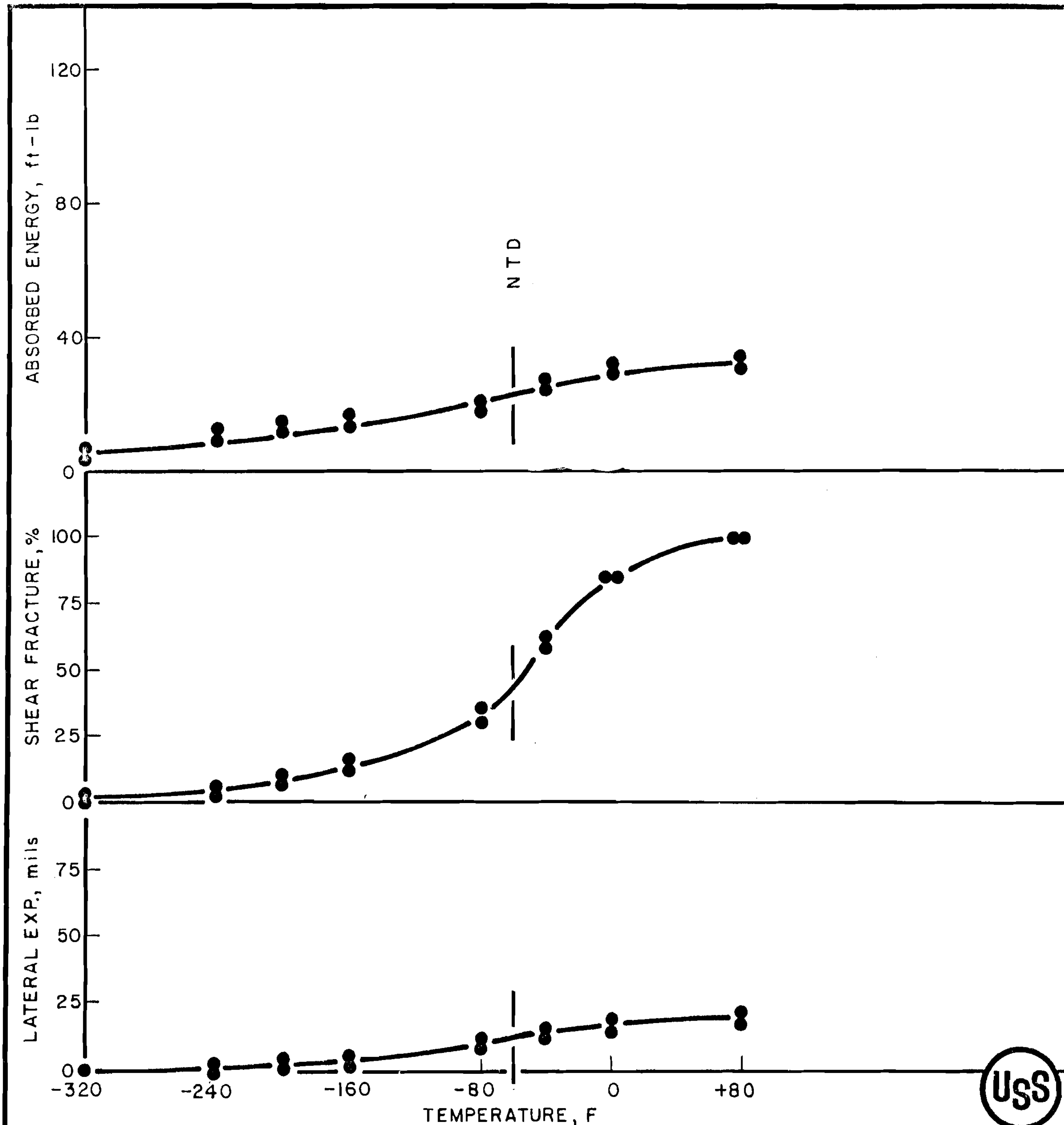
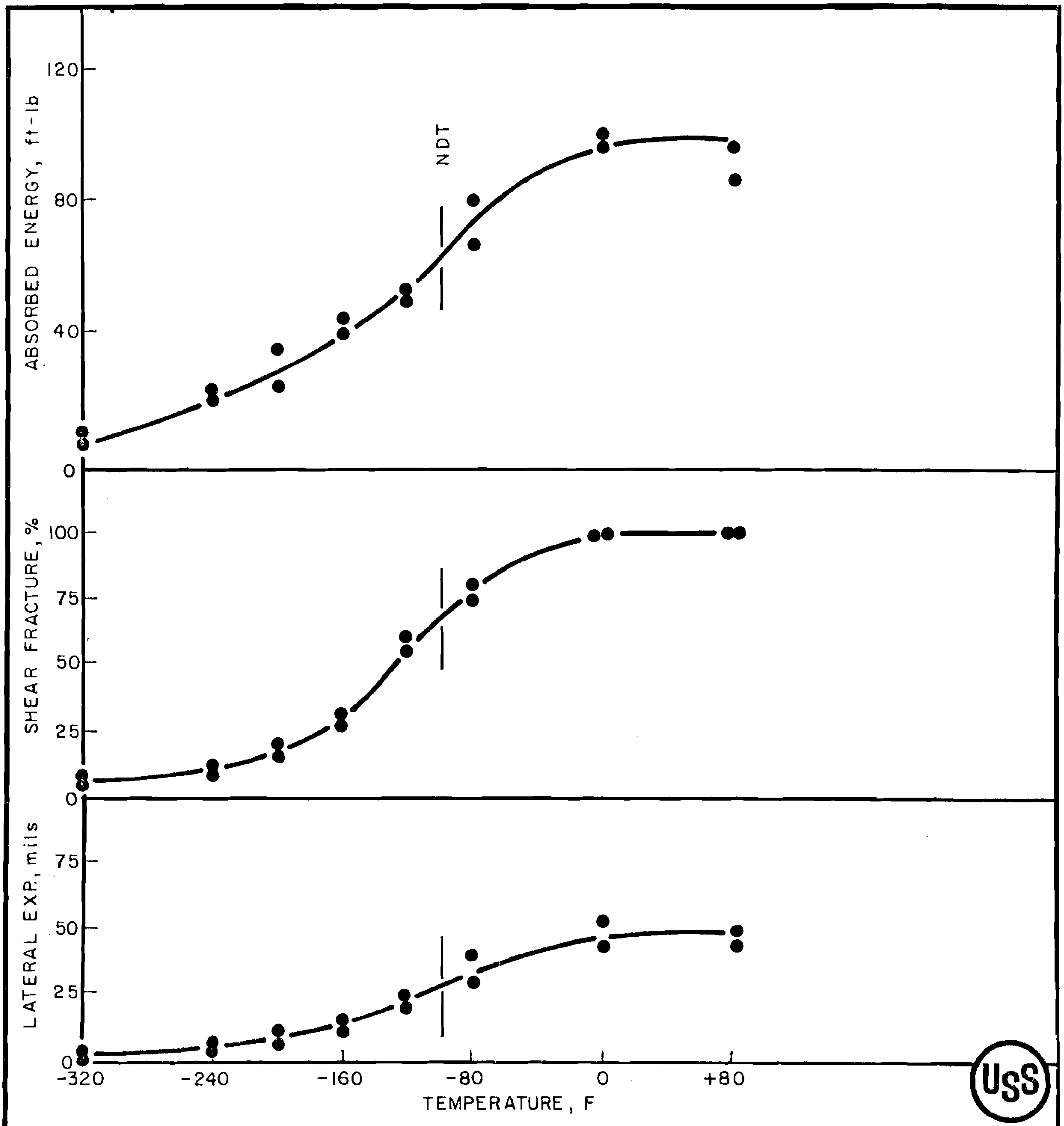


CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1-INCH-THICK HY-80 STEEL HEAT-TREATED TO 150 KSI YIELD STRENGTH

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	9
DRAWING No.		PROJECT No.	PITTSBURGH, PA.	
ARL 18-311		40.018-001(19)		
		DATE		
		3-11-64		

G18242 REV. 357



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1-INCH-THICK
3-3/4 Ni-Cr-Mo-V STEEL

DRAWN BY G.A.Z.	CHK'D BY S.T.R.	APPROVED BY J.H.G.	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. 10
DRAWING No. ARL 18-312		PROJECT No. 40.018-001 (19) DATE 3-12-64		

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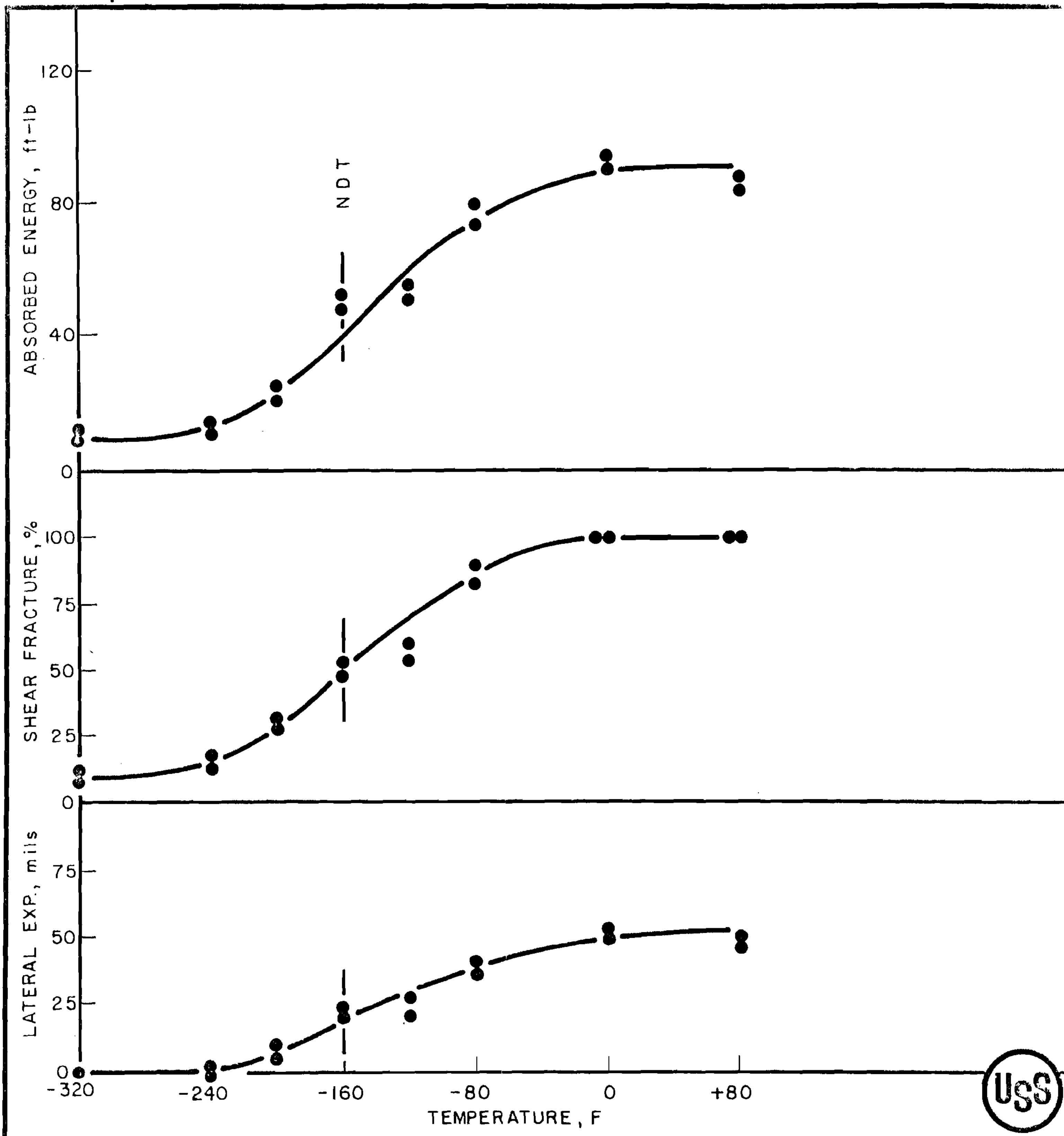
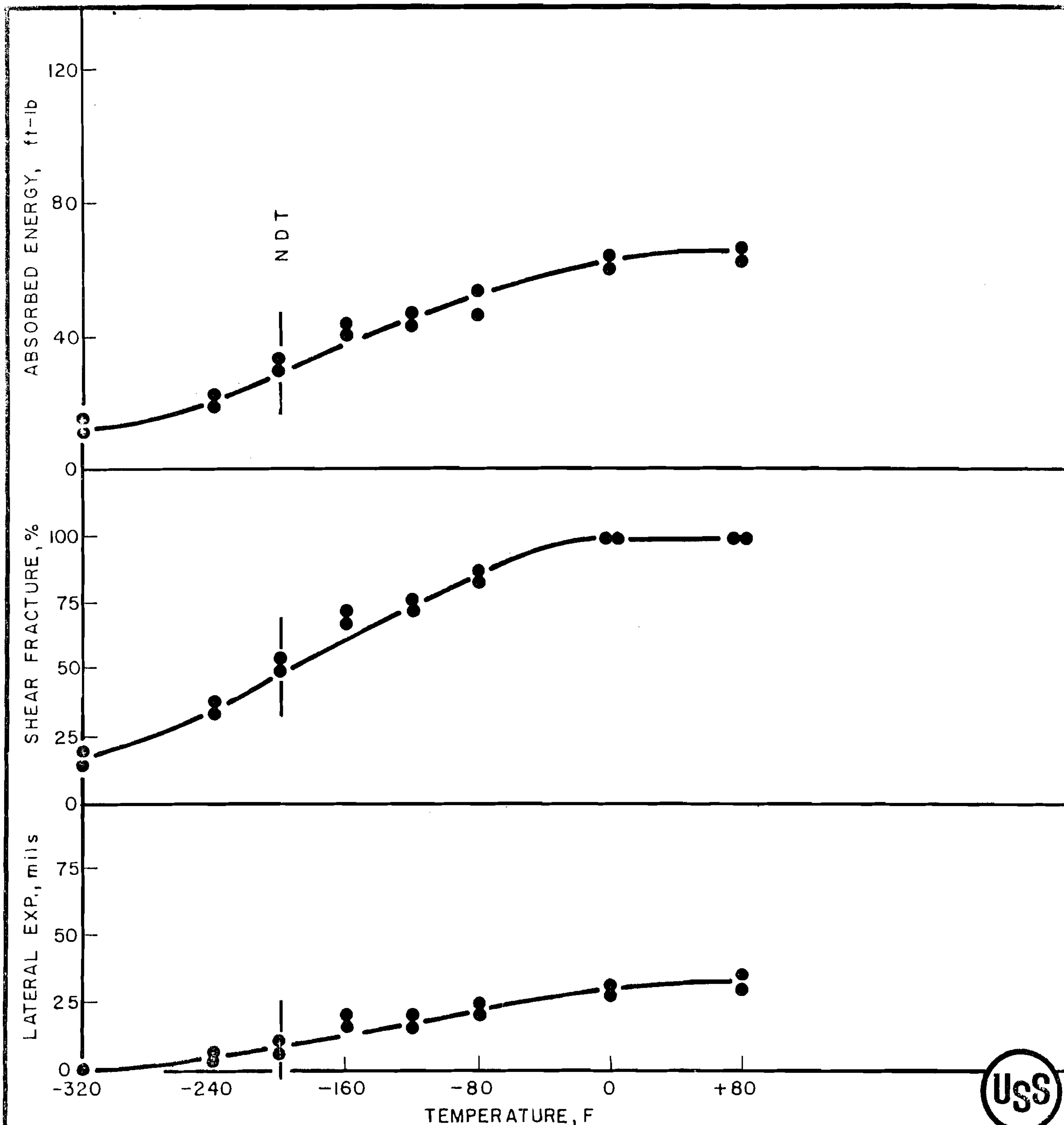
G18242 REV. 3-57



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1-INCH-THICK 5-1/4 Ni-Cr-Mo-V STEEL

DRAWN BY G.A.Z.	CHK'D BY S.T.R.	APPROVED BY J.H.G.	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. 11
DRAWING No. ARL 18-313		PROJECT No. 40.018-001(19) DATE 3-13-64		

G18242 REV. 3-57



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1-INCH-THICK 7-1/2 Ni-Cr-Mo STEEL

DRAWN BY G.A.Z.	CHK'D BY S.T.R.	APPROVED BY J.H.G.	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. 12
DRAWING No ARL 18-314		PROJECT No 40.018-001(19) DATE 3-13-64		

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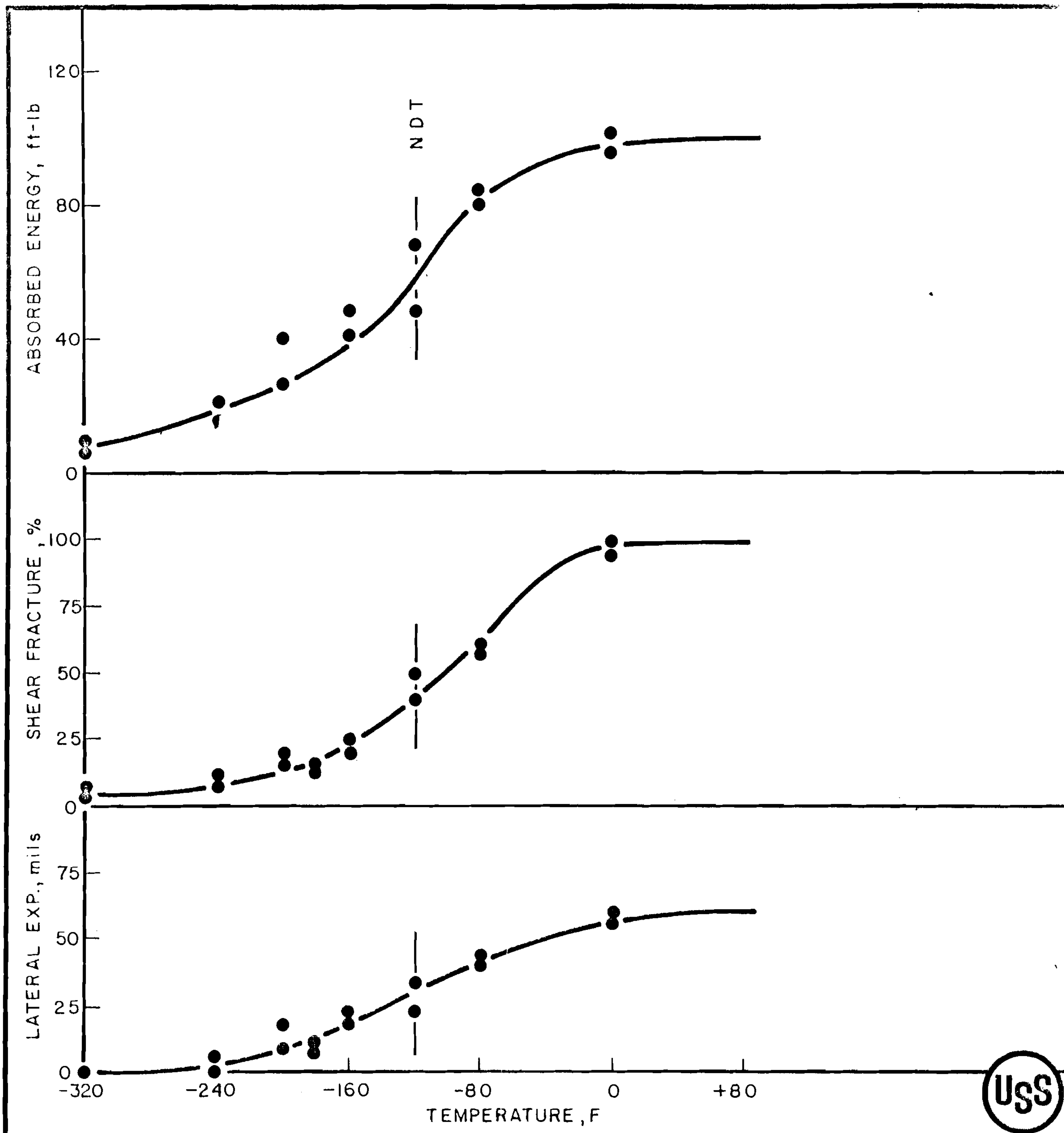
G18242 REV. 357



CHARPY V-NOTCH IMPACT TEST RESULTS FOR 1-INCH-THICK
5 Ni-Cr-Mo-V STEEL

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.T.R.	J.H.G.	APPLIED RESEARCH	13
DRAWING No.		PROJECT No. 40.018-001(19)	PITTSBURGH, PA.	
ARL 18-315		DATE 3-13-64		